COMPARISON BETWEEN EXISTING INSPECTION TECHNIQUES FOR EUV MASK DEFECTS

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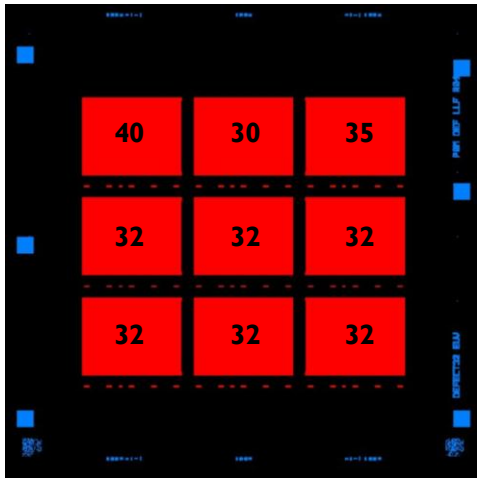
INTRODUCTION

Goal of this investigation: Is it possible to find **printing, natural reticle** defects **(32nm node)** with wafer inspection, that were missed by **existing** blank inspection or patterned mask inspection.

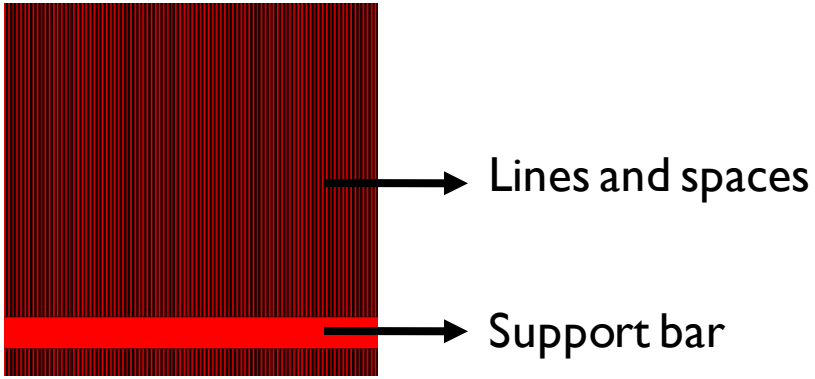
- **Printing:** only defects verified printing on wafers exposed on ADT
- **32nm node:** to assure appropriate process window throughout ADT full-field
- **Natural:**
  - Focus is on defects that are in the ML or absorber; excluding particles
  - Opposite to programmed defects
- **Existing:** the most state-of-the-art available at tool vendors and/or in use in the field for state-of-the-art applications, both for patterned mask inspection **(PMI),** blank inspection **(BI)** and wafer inspection **(WI).**

RETICLE LAYOUT: DEFECT RETICLES

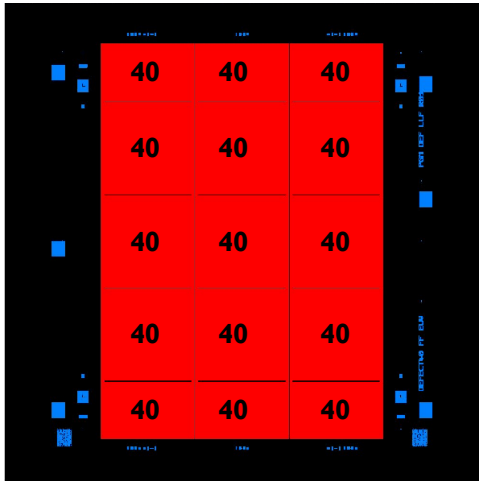
DEFECT32



- Sub-modules to allow **die-to-die inspection** (PMI)
- Vertical lines and spaces => **maximum printability**
- **Support bars** to prevent pattern collapse



DEFECT40FF(A+B)



- **Cell-to-cell WI** is possible => WI can detect **repeater** defects (=reticle defects)
- Various **pitch-dimensions**
- Matrix of **programmed defects** (known sizes and types) to verify sensitivity of each technique

INTRODUCTION: DEFECT32 METROLOGY BENCHMARKING

BI after ML-deposition
Lasertec M1350 (standard BI)

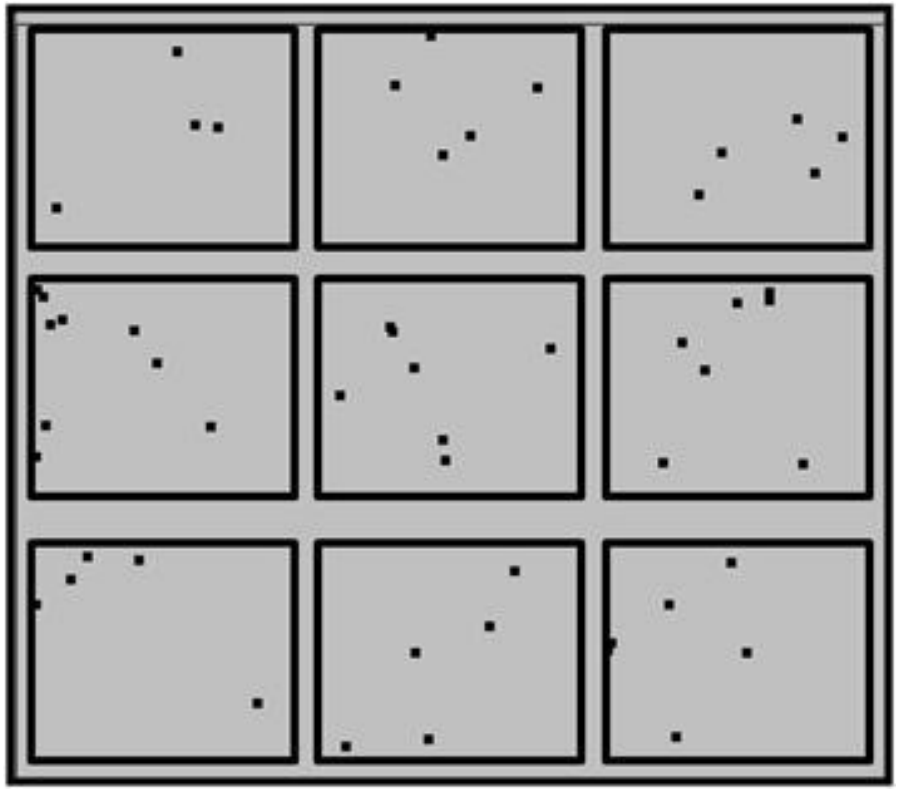
BI after absorber deposition
Lasertec M1350

4 different PMI:
- **Standard inspection mask shop**
- **3 more state-of-the-art tools**

5 different WI:
- **Standard KLA2800 inspection at IMEC**
- **4 more state-of-the-art tools**

All locations reviewed on 1 wafer

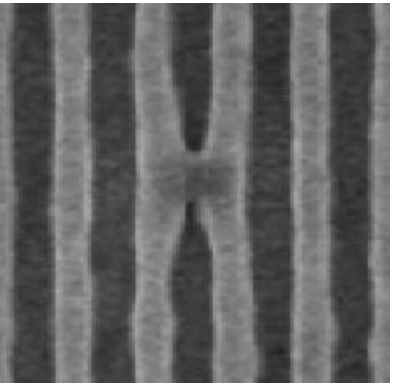
MAP (reference wafer)



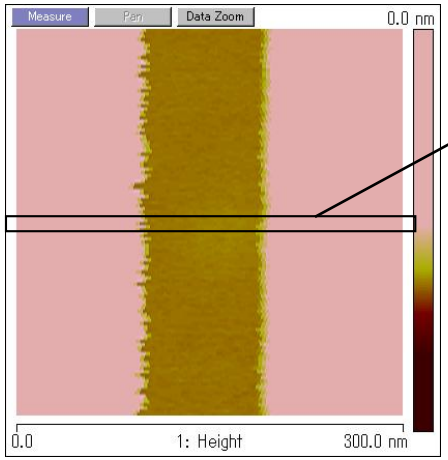
48 printing defects in total

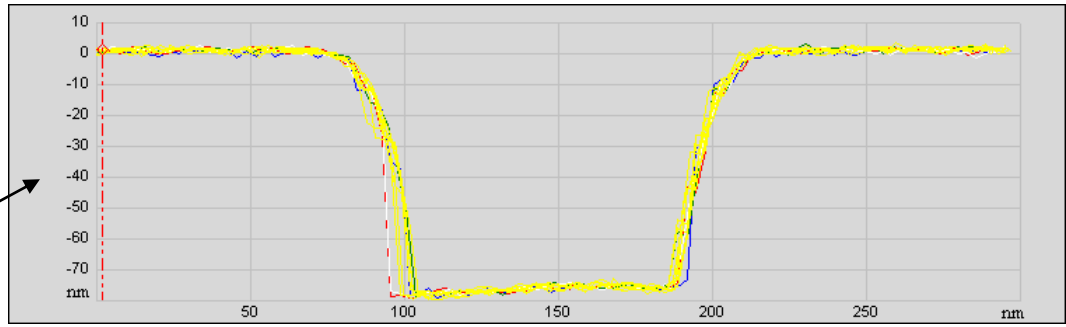
DEFECT REVIEW FOR 48 DEFECTS

Defect on wafer

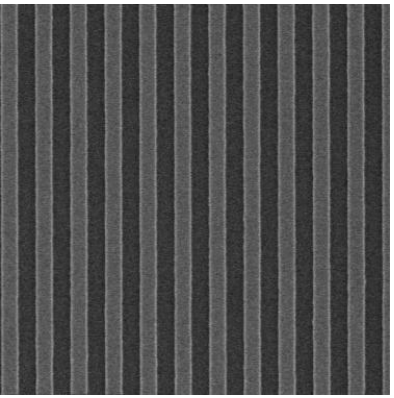


Horizontal scan

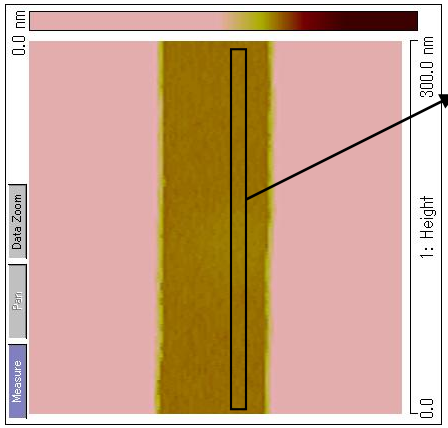


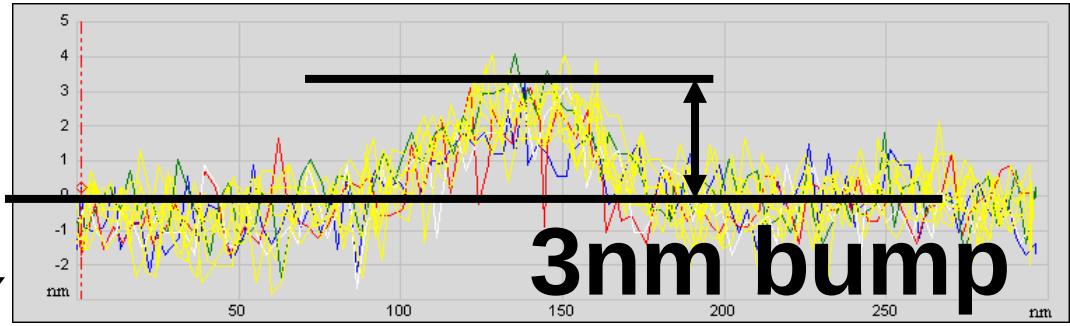


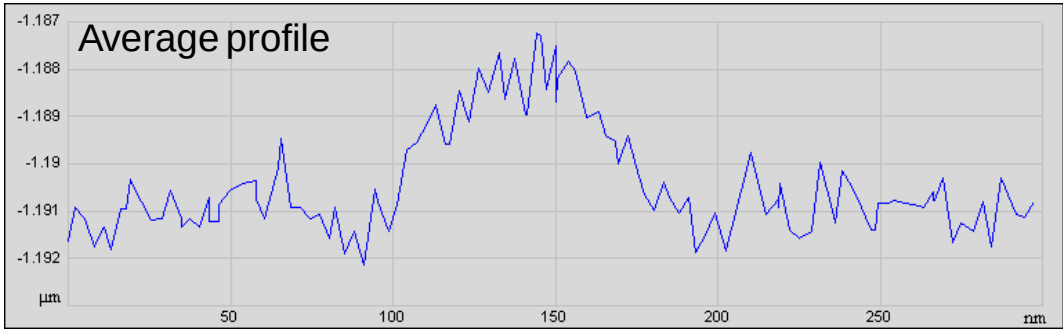
Defect on mask



Vertical scan

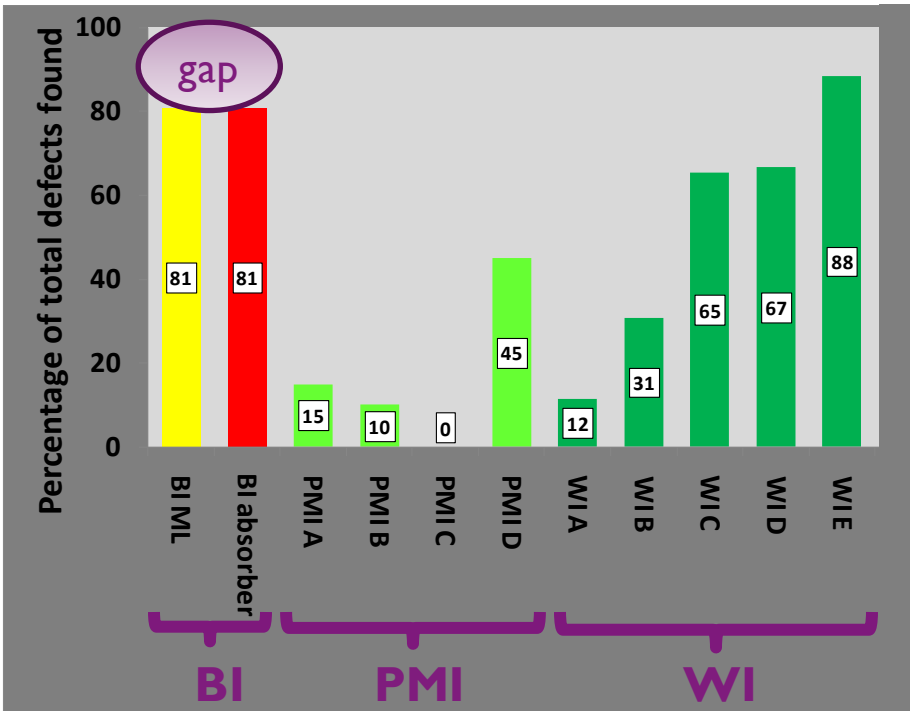




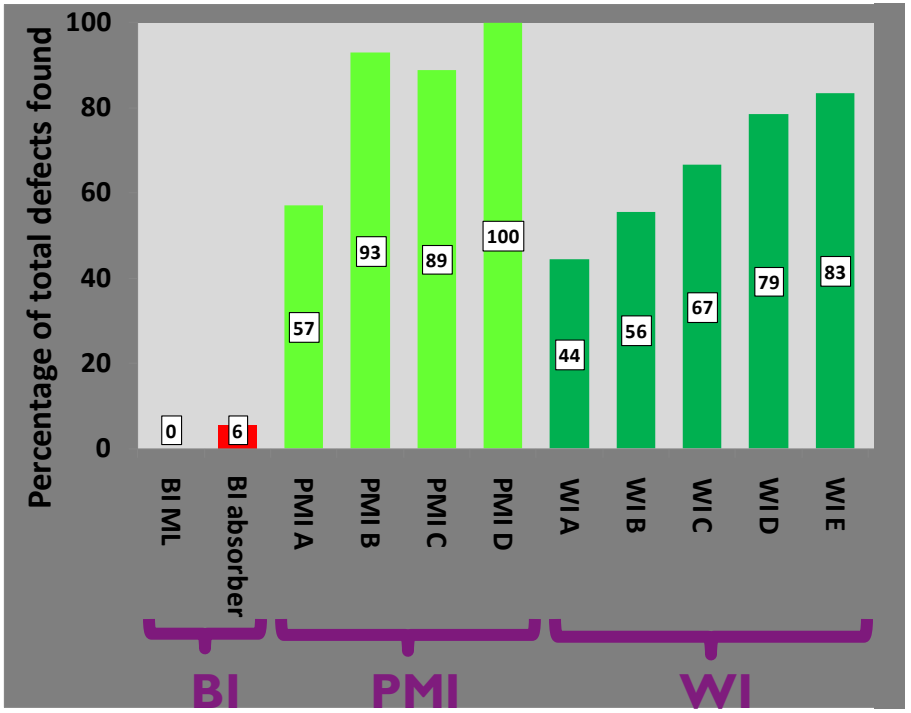


SENSITIVITY FOR ML AND ABSORBER DEFECTS SEPARATELY

ML DEFECTS



absorber DEFECTS



Conclusion: absorber defects are more likely to be detected (and also more likely to be repairable)
=> ML defects is biggest concern

SUMMARY DEF32 METROLOGY BENCHMARKING

- Standard **M1350 Blank Inspection** failed to find certain known printing ML defects
- Capture rate **Patterned mask inspection**:
  - For **Absorber** defects **100%** is possible
  - is **low** for **ML**-defects
- With AFM-review on mask we found proof of a natural **3nm bump** in ML **causing killer defect**.

SECOND RETICLE: DEFECT40FF-A INVESTIGATION FOR ML DEFECTS

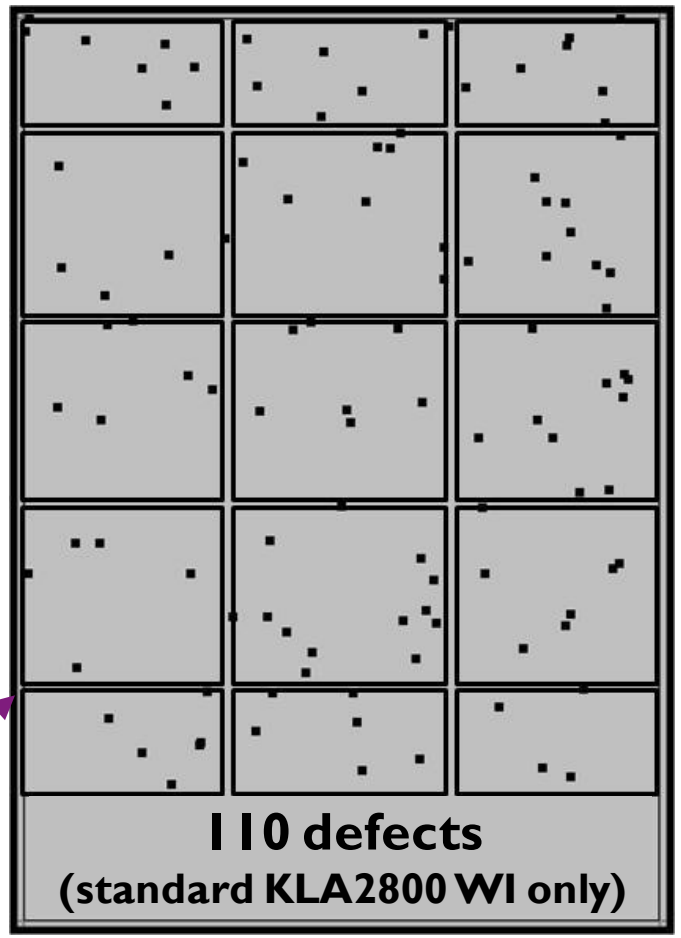
BI after ML-deposition on Lasertec M1350

BI after absorber deposition on Lasertec M1350

BI after ML-deposition on Lasertec M7360 (= state-of-the-art)

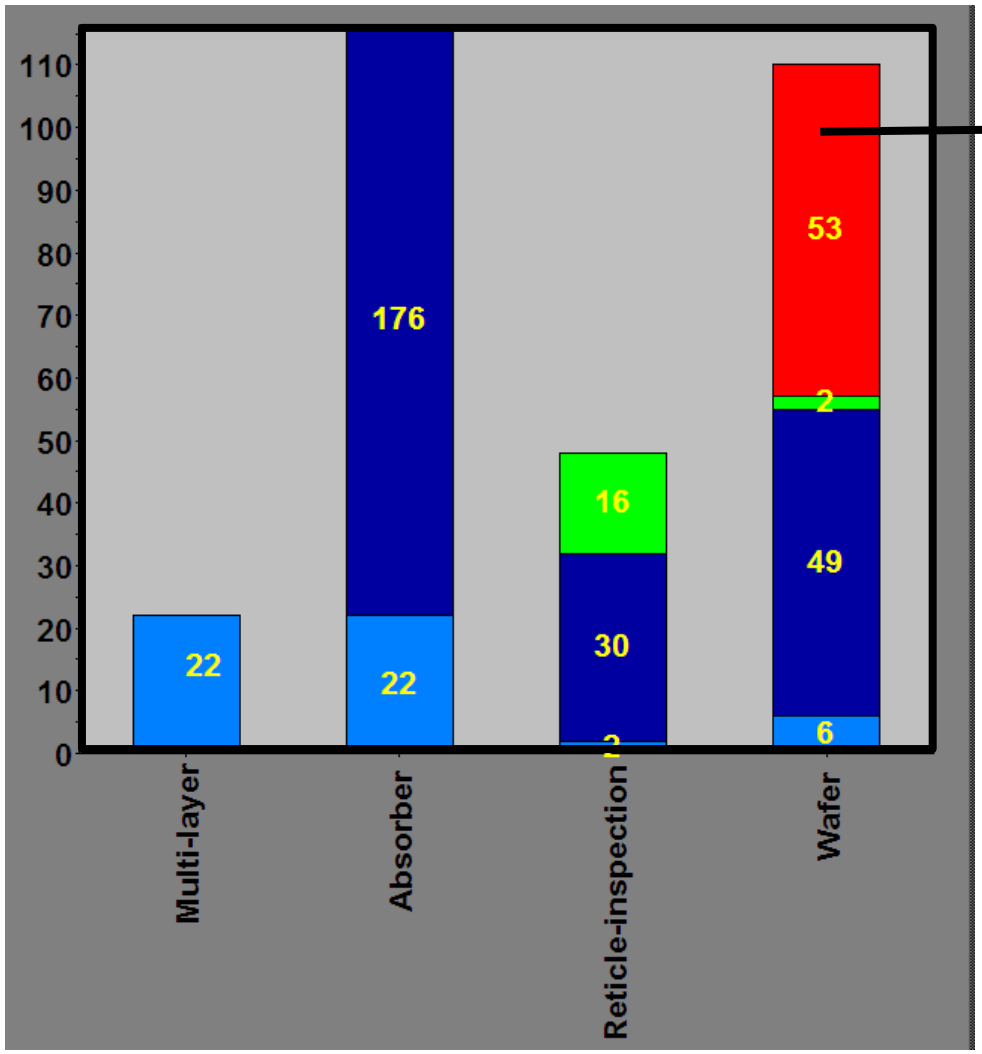
Standard PMI with Mask vendor

KLA2800WI in IMEC



Remark: No PMI or WI on more state-of-the-art inspection tools.

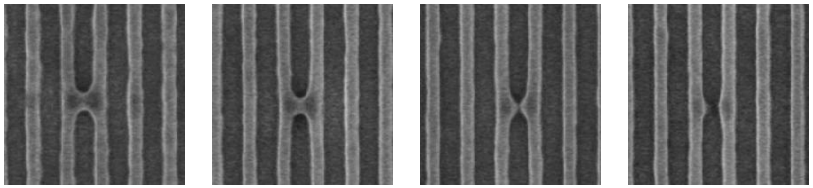
CORRELATION BI (M1350), PMI AND WI WITH DEFECT SOURCE ANALYSIS (DSA)



53 defects only found by wafer inspection => good candidates to be similar ML-defects as on DEF32

Focus-test to get extra indication which defects could be ML-defects :

Ref: Chris H. Clifford et al, EUVL symposium 2009

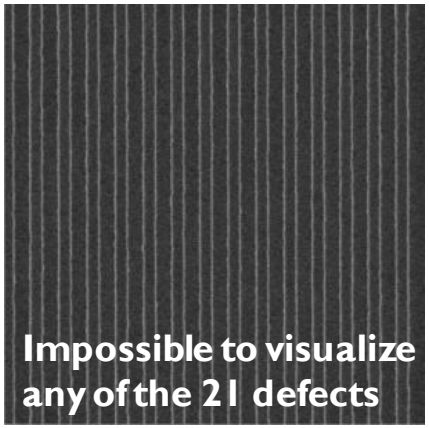


+0.15um +0.10um 0.00um -0.10um

21/53 show very strong focus-behavior

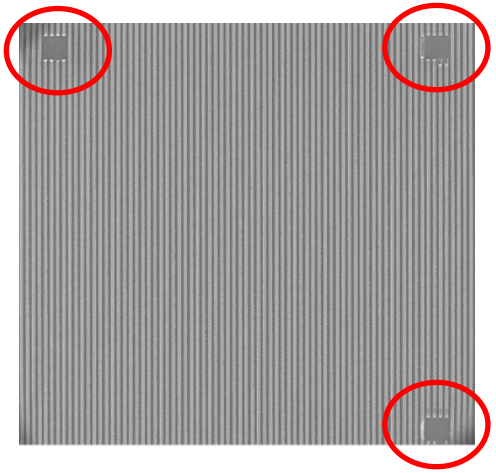
RETICLE REVIEW OF CANDIDATE ML-DEFECTS MISSED BY M1350 INSPECTION

SEM-review on mask

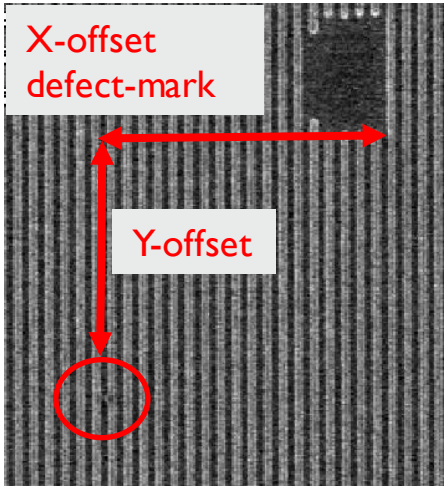


AFM-review on mask

Reticle marks



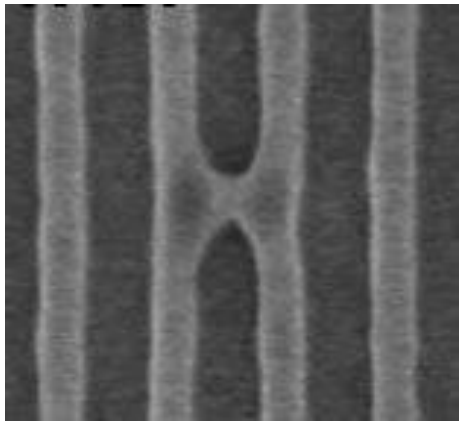
Print wafer on IMEC ADT and check defect location with marks

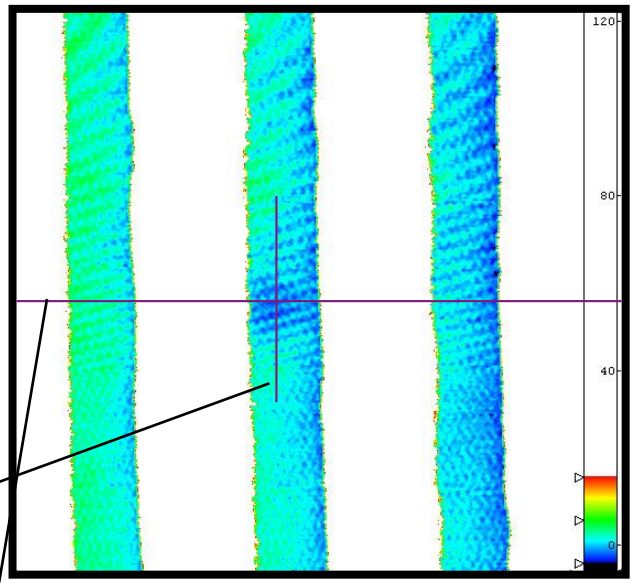


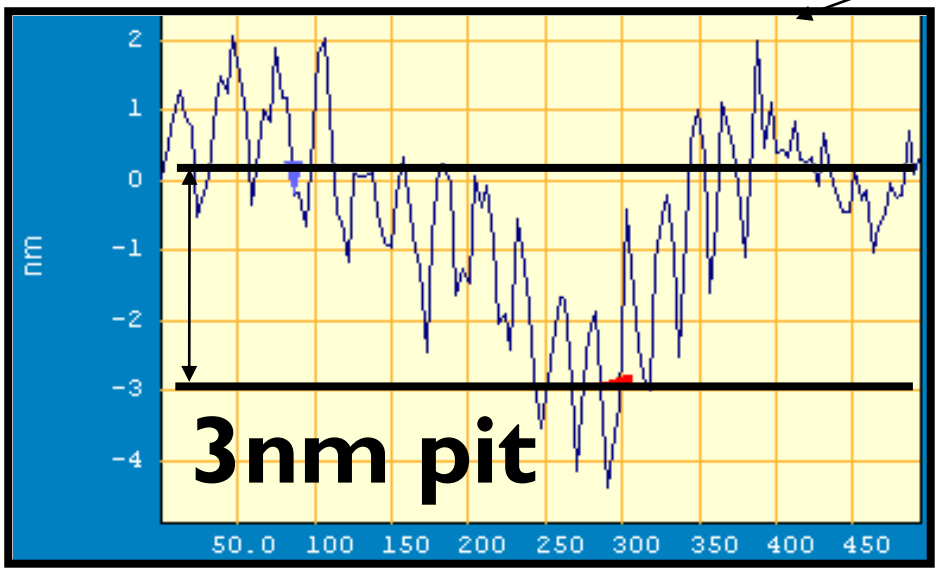
New attempt with AFM with better alignment (reduced search range)

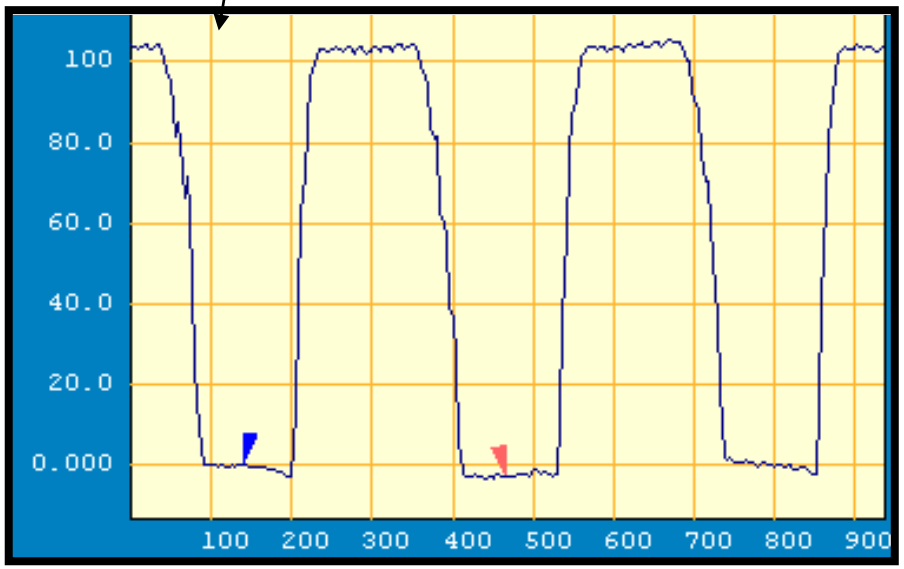
2ND ROUND OF AFM: RESULTS

Wafer review

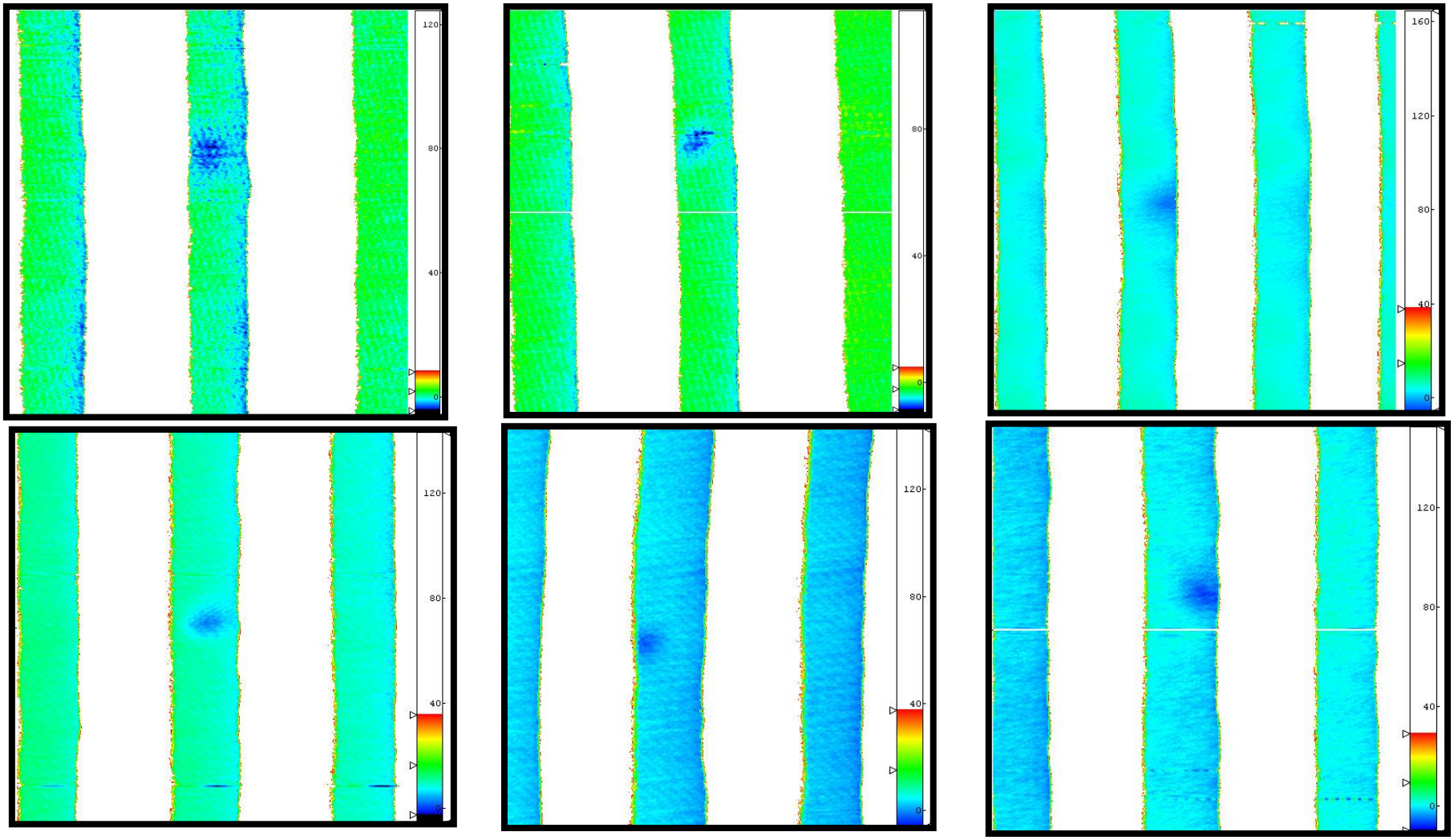






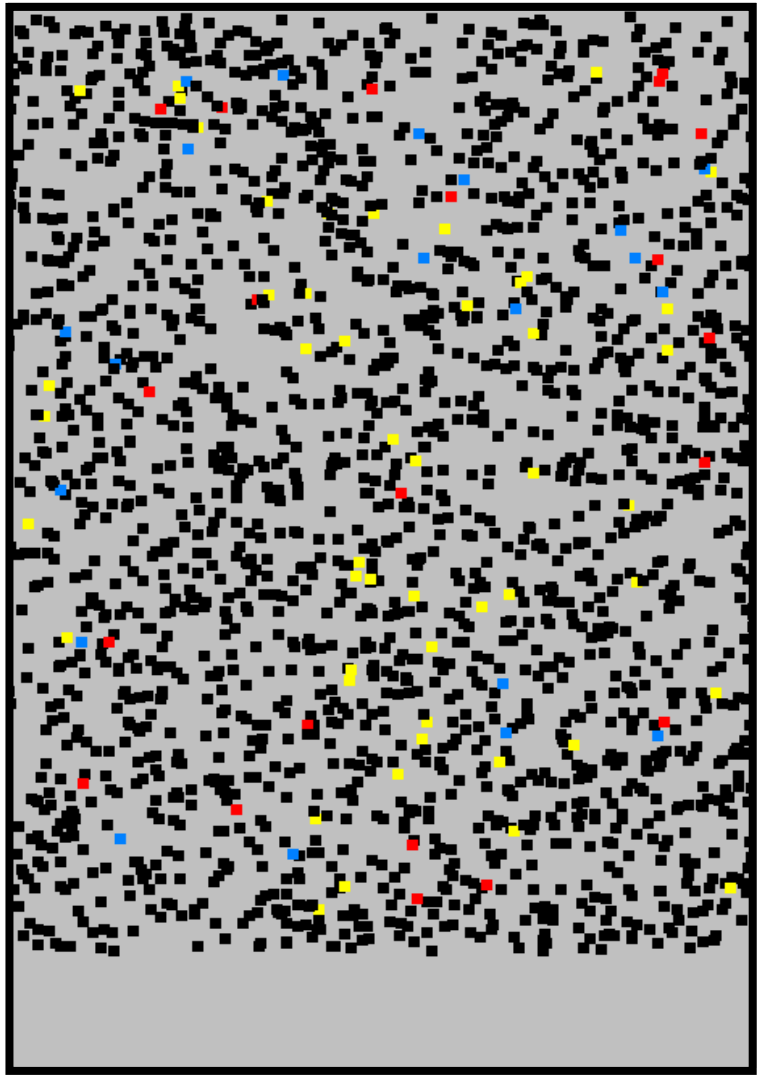


MORE EXAMPLES



Out of 21 candidate ML defects, 14 were checked with AFM and all were ML pits between 3-7nm!!

WHAT ABOUT MORE ADVANCED BLANK INSPECTION (M7360)?



1. **Did M7360 detect these 21 defects?**

   All 21 defects were detected (red dots)

2. **Reticle review revealed not 21, but in total 41 defects that were related to ML (no focus effect). Did M7360 find all these defects?**

   All 41 defects were detected (red + blue dots)

3. **Review of additional detections by M7360 on wafer => how many print?**

   An additional 50 printing defects were detected (yellow dots)

4. **Review of additional detections by M7360 on wafers => how many don't print?**

   The amount of detections of non-printing defects (black dots) is unacceptable

   Note: locations were only reviewed in BF

5. **Important remark: state-of-the-art wafer inspection tools might reveal smaller, even more-challenging ML-defects that might have been missed by M7360-inspection (future work)**

SUMMARY DEFECT40FF-A RESULTS

- Confirmation that standard **Lasertec M1350 Blank Inspection** misses certain printing ML-defects
- More advanced **Lasertec M7360**:
  - All **known** printing ML-defects were detected (no data of state-of-the-art WI available)
  - Too many **nuisance** detections
- With AFM-review on mask we found proof of a natural **3nm pit** in ML **causing killer defect**.

THIRD RETICLE: DEFECT40FF-B INVESTIGATION FOR ML DEFECTS

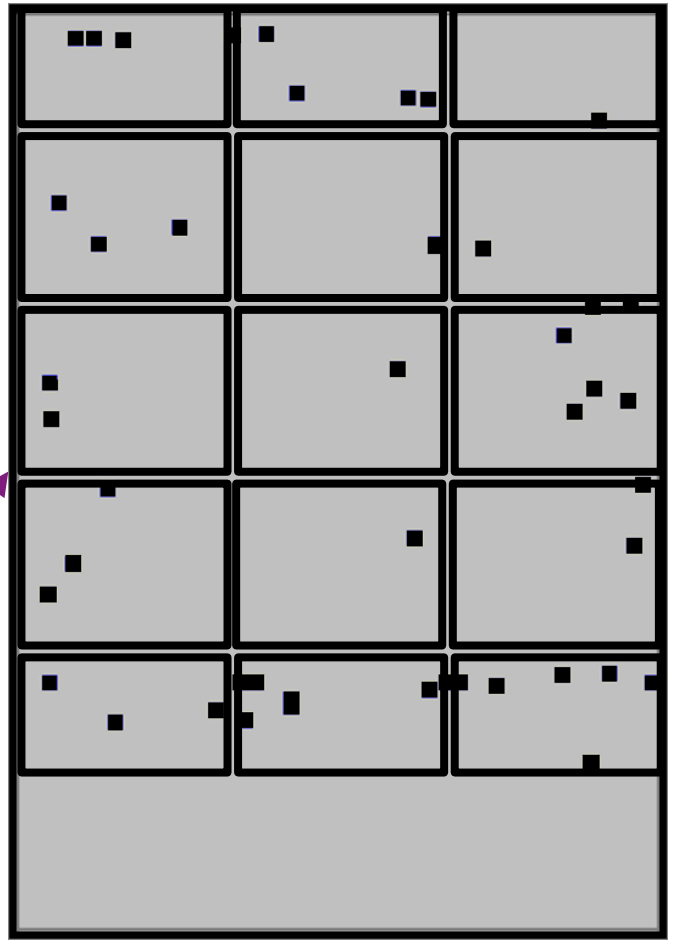
Substrate inspection on Lasertec M1350

BI after **ML** deposition on Lasertec **M7360**

BI after **absorber** deposition on Lasertec M1350

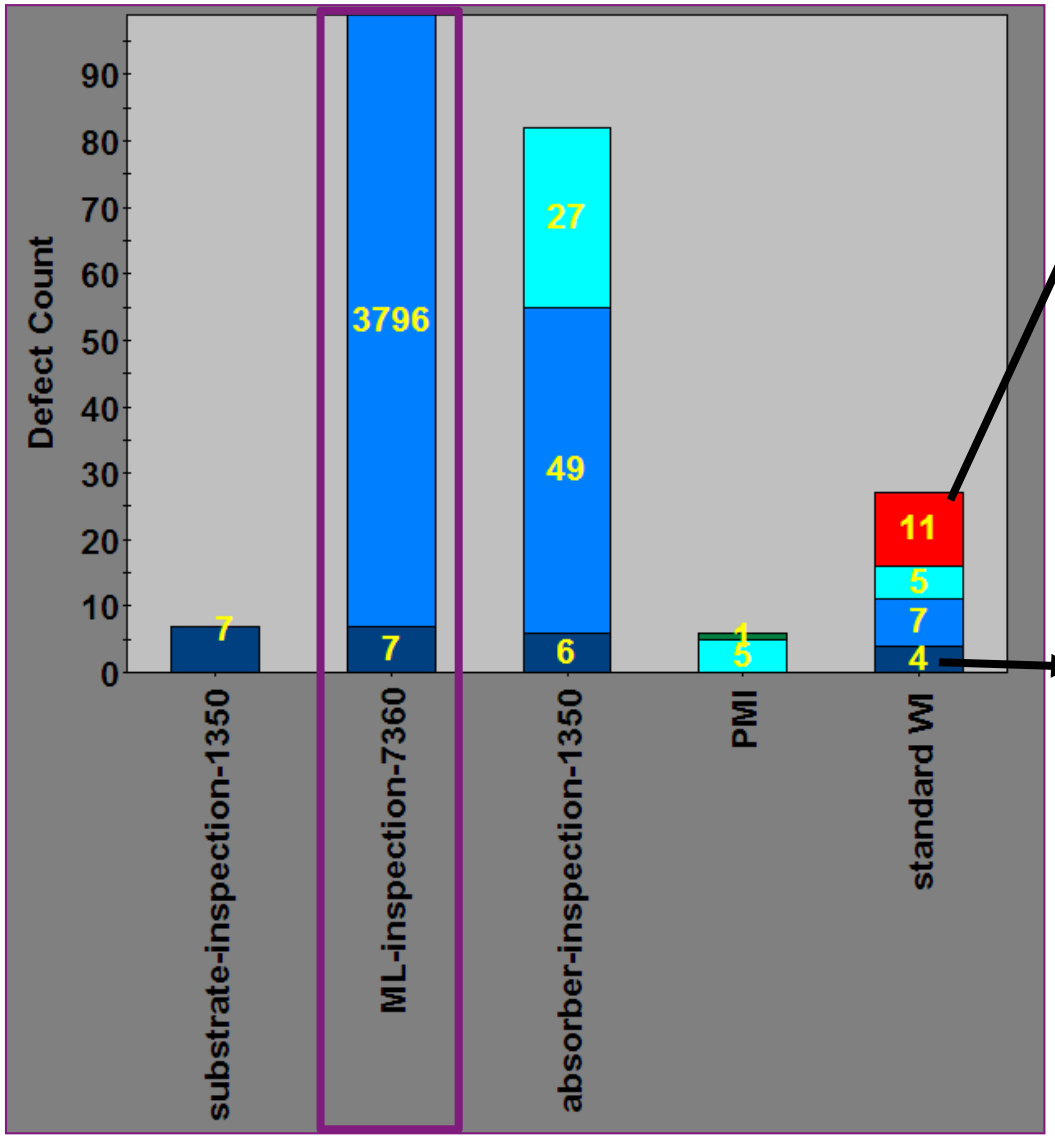
Standard **PMI** with Mask vendor

KLA2800 WI in IMEC
+
Optimized WI procedure on more **state-of-the-art** WI-tool

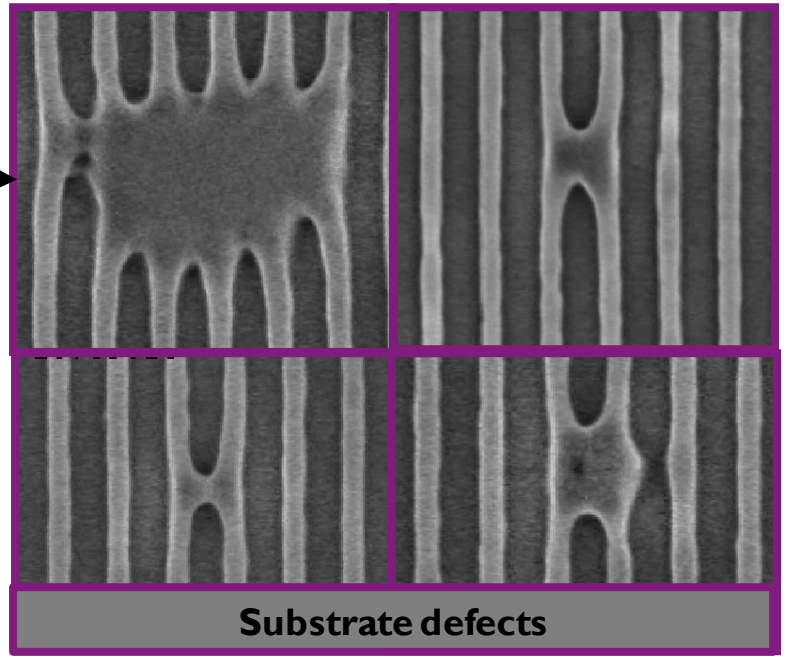


KLA2800: 27 defects

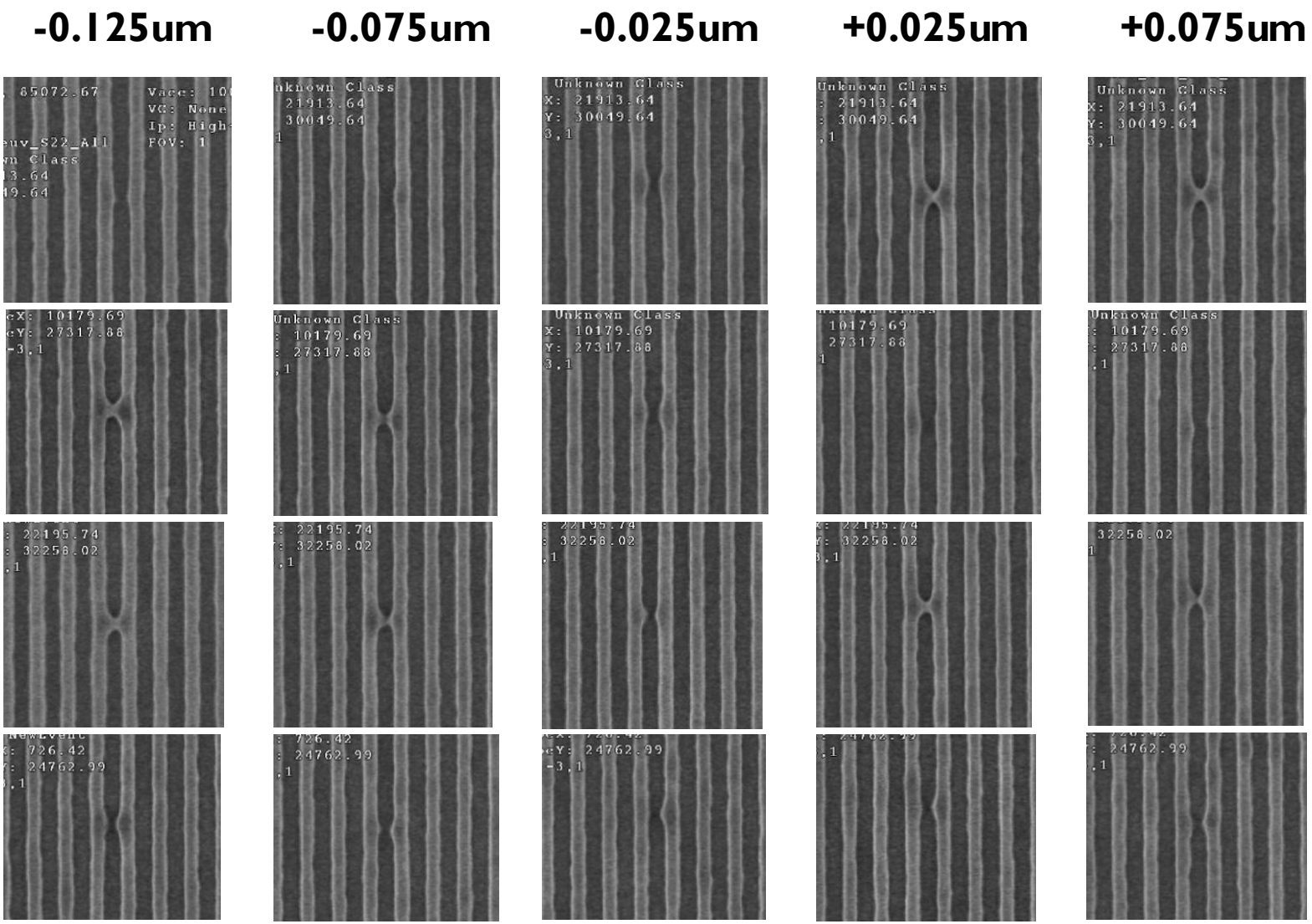
DEFECT40FF-B: DSA RESULTS



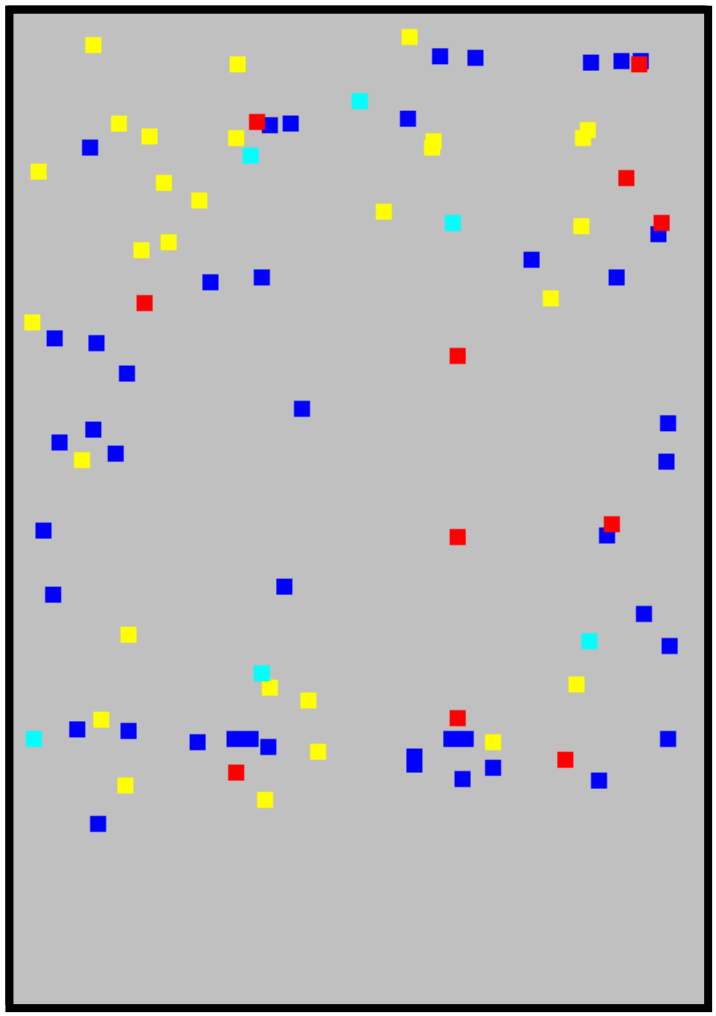
- Mostly particles, 1-2 defects with minor focus behavior
- What if we try to improve WI?



FOCUS BEHAVIOR ML-DEFECTS

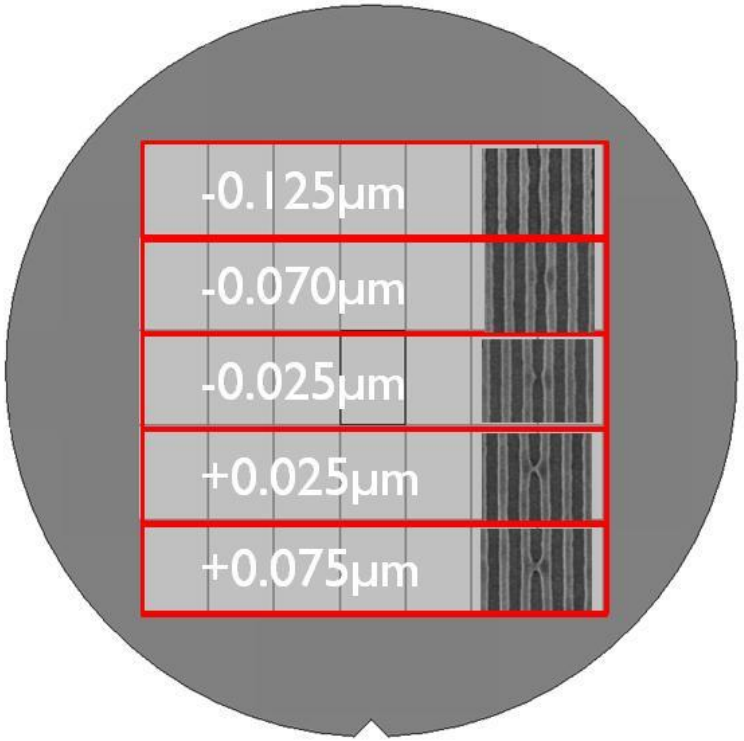


IMPROVEMENT OF WAFER INSPECTION TECHNIQUE



KLA 2800 WI in best focus (BF)

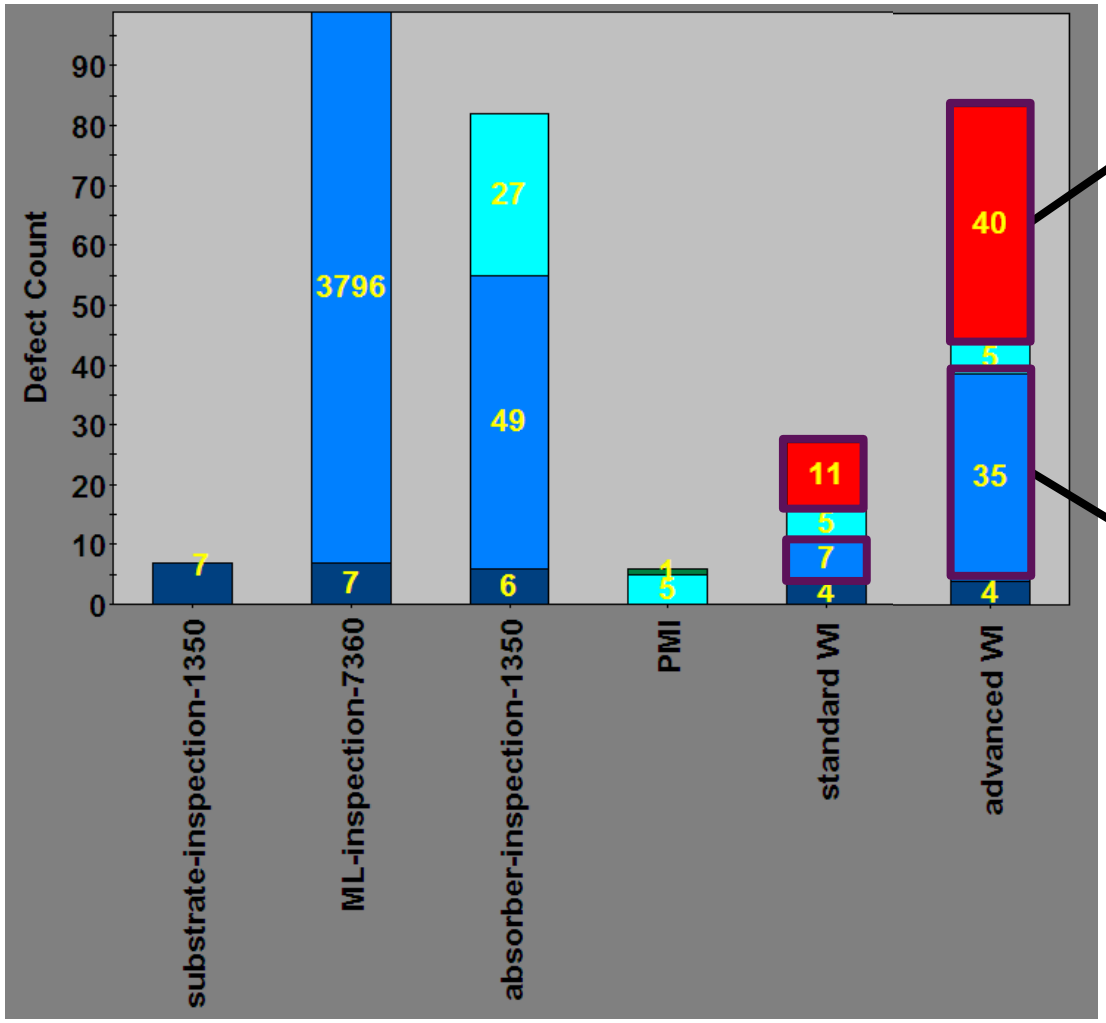
KLA2800 WI on focus-skew wafer



Advanced WI (AMAT UVI 4) in BF

Advanced WI (AMAT UVI 4) on focus-skew wafers

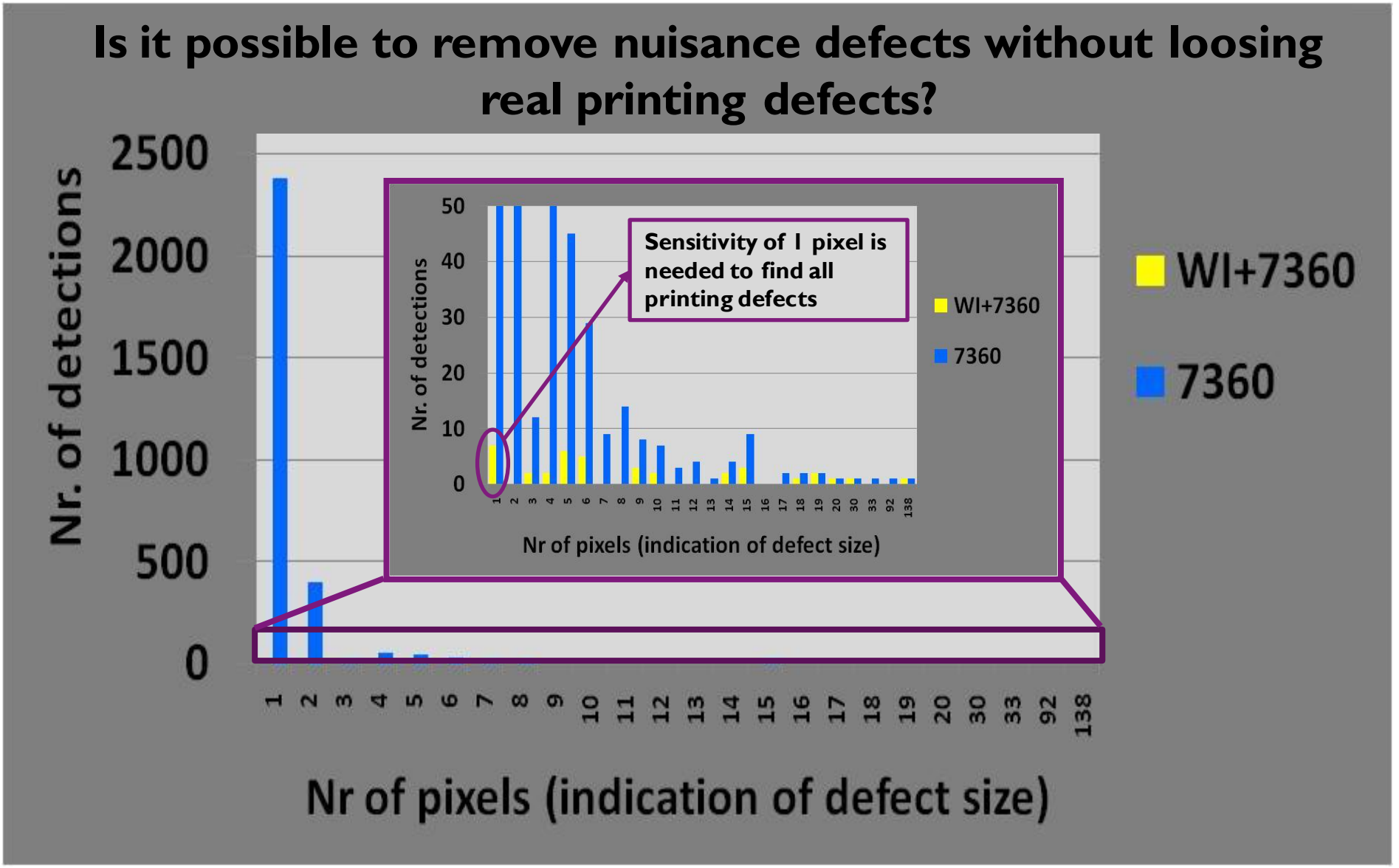
DEFECT40FF-B: DSA WITH OPTIMIZED WI



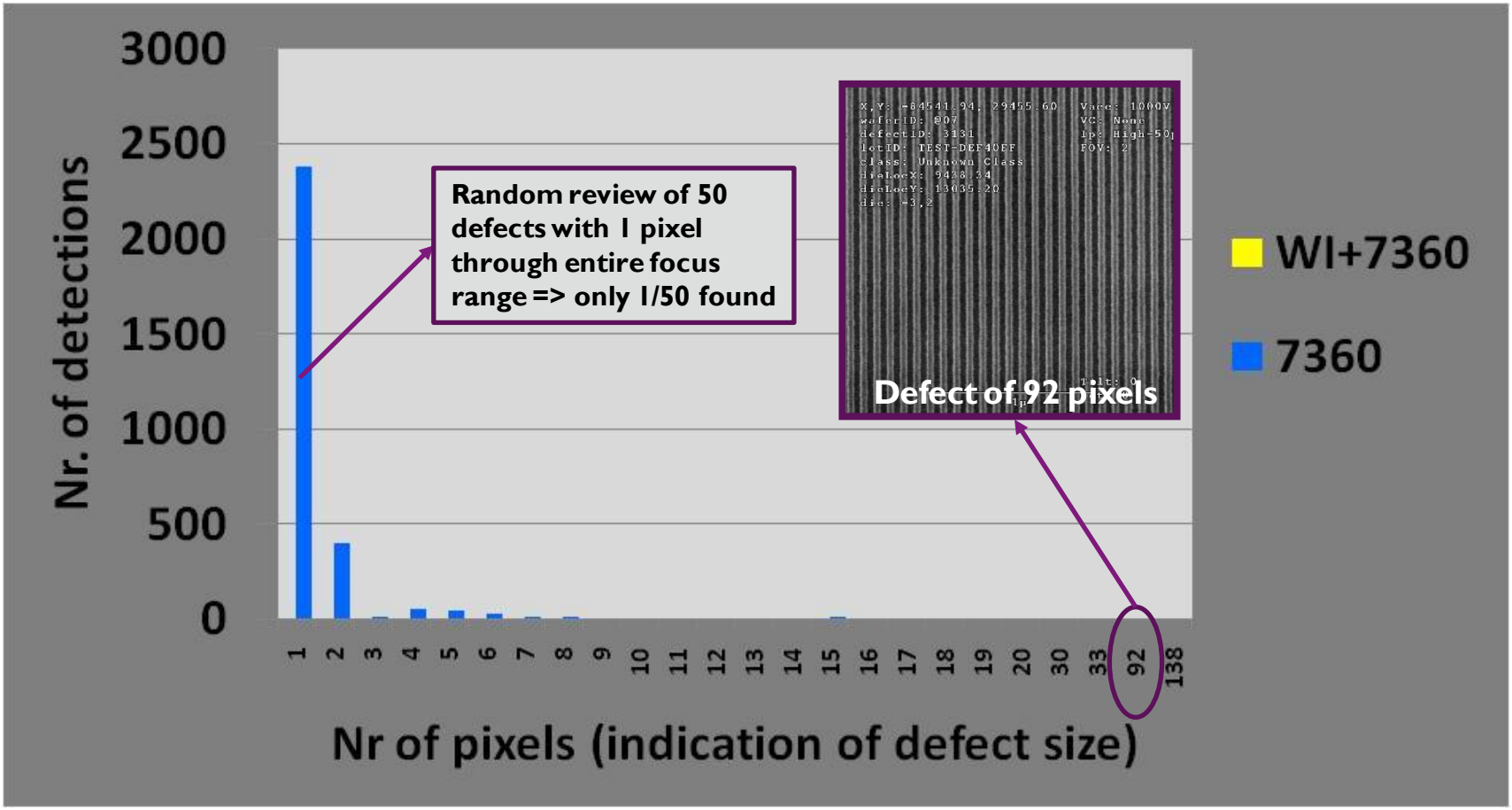
Nr. of defects only found by WI also increases significantly

Number of defects correlating with BI increases significantly

NUISANCE RATE M7360

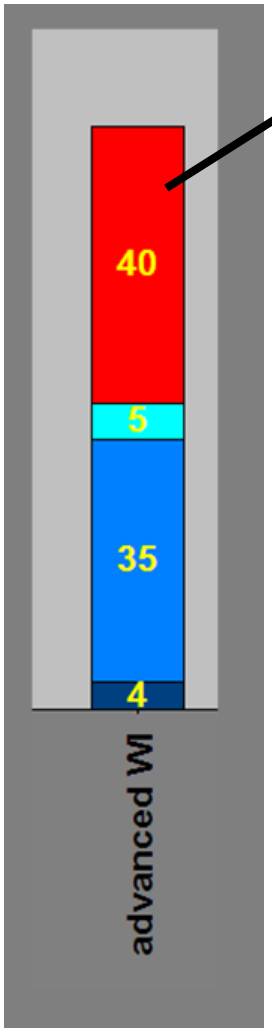


REVIEW OF DETECTIONS MADE BY 7360

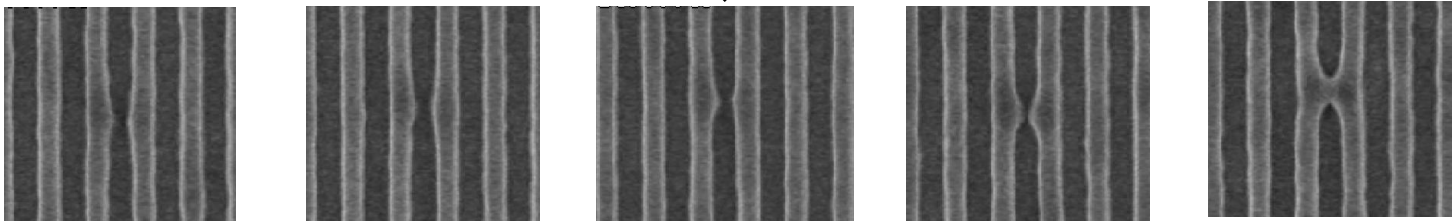


Major challenge for optical blank inspection will be to differentiate between defects that are likely to print and defects that are not likely to print

DEFECTS ONLY FOUND BY WAFER INSPECTION



40 defects only found by wafer inspection



From – to + focus offset

At least 10 defects show through-focus behavior

Currently AFM analysis is ongoing

OVERALL CONCLUSIONS

- **Patterned Mask Inspection**:

all known printing absorber defects can be found, but most advanced PMI-tools are needed

- **BI standard Lasertec M1350**:

on all 3 reticles printing ML defects were missed

- **Blank inspection M7360** :

1. Nuisance rate (=non-printing defects) is too high
2. Strong evidence for M7360 failures, yet working on a proof via visualization by AFM

- Proof of both **natural bumps and pits with only 3nm height distortion on ML-surface** , causing killer defects on wafer

  => Maybe optical inspection techniques are limited for these types of defects, because they cannot penetrate inside ML

ACKNOWLEDGEMENTS

- Tool vendors:
  - Applied Materials
  - KLA-Tencor
  - Nuflare
  - Hermes Microvision
- INTEL: Sang Lee, Michael Leeson
- Carl Zeiss: Thorsten Hofmann, Markus Waiblinger
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- IMEC colleagues: Jan Hermans, Bart Baudemprez, Rudi De Ruyter, ...
- ASML ADT-team in IMEC
- All of you, for your attention

Thank you!

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